REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY

Rocky Flats Plant Site

Task 12
of the
Zero-Offsite Water-Discharge Study

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EXECUTIVE SUMMARY

This report is one of several being conducted for and in the development of a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE)(ASI, 1990a). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate discharges to the environment including surface waters and groundwater. This review should include a source reduction review."

Specifically, this report addresses the continued use of multiple effect mechanical evaporation at the RFP, system upgrades and system evaporation load management alternatives. The context of this effort are Task 10, Sanitary Treatment Plant Evaluation (ASI, 1991a), and Tasks 11/13, Treated Sewage/Process Wastewater Recycle Study, (ASI, 1991b).

A water balance for the entire plant was developed as part of the Tasks 11/13 studies. For calendar year (CY) 1989, 121 million gallons (MG) of water was purchased from the Denver Water Board (DWB), while 74 MG of sanitary treatment plant effluent was discharged. The Tasks 11/13 study recommended a water recycle effort that would utilize treated domestic wastewater for cooling tower and other non-potable water uses at RFP. This recommendation was made assuming the Task 10 STP upgrade and pretreatment facilities recommendations were strictly adhered to. Salt buildup in the recycle stream was to be controlled by periodic operation of a sidestream reverse osmosis (RO) loop and subsequent salt concentration by vapor compression evaporation (VCE).

Process wastewaters at RFP are separately collected, transported and treated at Building 374. Existing process wastewater pretreatment facilities are followed by multiple effect mechanical evaporation of all remaining liquid volumes. This evaporator, originally designed for treating (evaporating) 21 million gallons per year (MGY), has been operating at near capacity, 13-14 million gallons per year, to treat the process wastewater volume, solar evaporation pond volume scheduled for closure, solar pond interceptor trench water volumes and other difficult to treat water volumes at RFP. Insufficient storage for these volumes stresses the evaporator system even further.

System Alternatives

This study presents a series of potential alternatives to the use of the existing multiple effect mechanical evaporation system for salt concentration at the RFP. These alternatives include the use of waste heat concentration, reverse osmosis, vapor compression evaporation and multiple effect mechanical evaporation in either series or parallel operation. The selection of an alternative is highly dependent on RFP utility costs. The final alternative selection process should be preceded or parallelled with an energy audit to accurately reflect potential economics.

It is extremely important, as was stated in the Tasks 10 and 11/13 studies, that pretreatment of sanitary or process wastewaters be accomplished with full knowledge of the effects on downstream operations, whether reverse osmosis, vapor compression or multiple effect evaporation. In the absence of such pretreatment, any RFP wastewater treatment and reuse system will be negatively affected, with water saving benefits reduced significantly and, perhaps, system failure.

An alternative that utilizes membrane treatment, ultrafiltration followed by reverse osmosis, of process wastewater could increase the existing multiple effect evaporator (MEE) system capacity by approximately 9 MGY. Use of membranes in the process wastewater loop was subsequently rejected in light of the wide variety of flow rates and contaminants in this wastewater volume.

The use of vapor compression concentration in series or parallel with the existing multiple effect evaporator represents the salt concentration alternative of choice for RFP. The reverse osmosis brine from the sanitary recycle system could be included in the process wastewater vapor compresssion/multiple effect evaporation system in lieu of a separate concentration step described earlier in this summary. In addition, brines from separate vapor compression evaporators which would be treating solar pond interceptor trench and landfill leachate water could be concentrated at the proposed VCE/MEE. Implementation of a VCE enhanced MEE evaporation system would increase the existing MEE system capacity by about 9 MGY for approximate capital costs of $1.5 million and provide much needed flexibility to the existing unit operation.

Recommendations

As the result of this study, it is recommended that the RFP implement a linked waste heat concentration, vapor compression and multiple effect evaporator system plumbed for series or parallel operation. Reverse osmosis brine from the sanitary recycle system along with the reverse osmosis brine from the landfill and the VCE brine from the solar pond interceptor trench system (SPITS) would be blowndown to the process wastewater collection system for treatment in a single vapor compression/multiple-effect evaporation system.

Also recommended are an energy audit of RFP, a tritium treatment pilot plant study and an overall RFP water reuse/recycle effort that recognizes the need for specific pretreatment of potential recycle water and thereby protects downstream investments in membrane separation and brine concentration evaporation systems.

Finally, all wastewater reuse/recycle treatment efforts must have strong administrative and operations management participation throughout the design, construction and operation/maintenance phases of the final reuse/recycle project.

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1.0 INTRODUCTION

Sound water resources management must include the potential reuse of properly treated wastewater as an alternative to meet current and projected water demands. The Environmental Protection Agency (EPA) views closed-cycle water systems as an ultimate goal for industrial plants for pollution control purposes alone (EPA, 1980).

Wastewater is a valuable resource and when properly treated and managed is suitable for many uses. An evaluation of the existing Rocky Flats Plant (RFP) wastewater treatment plant was completed under Task 10, Sanitary Treatment Plant Evaluation Study. (ASI, 1991a). A parallel effort, Tasks 11/13 Treated Sewage/Process Wastewater Recycle Study (ASI, 1991b), outlined water reuse opportunities associated with current and projected domestic and process wastewater streams. RFP currently utilizes two separate and distinct wastewater collection, transport and treatment systems. These are the domestic and process systems. The water reuse alternative of choice developed under Tasks 11/13 included ultrafiltration (UF) of biologically treated domestic wastewater, with reverse osmosis (RO) treatment to control reuse stream salt concentrations. The use of the words "ultrafiltration" and "reverse osmosis" in the Tasks 11/13 study referred to the general application of membrane processes for the purposes of RO pretreatment and subsequent desalting, respectively.

The entire spectrum of membrane treatment has changed significantly in the last 10-20 years, with RO system operating pressures typically dropping and the emergence of even lower pressure membrane systems for applications other than salt removal. Figure 1 depicts the current membrane treatment alternatives available. The selection of any specific membrane treatment system is a function of intended use: pretreatment or treatment and direct use. Associated with any membrane system are two additional areas of concern. First is the handling of concentrate streams, whether by surface water discharge, spray irrigation, evaporation ponds, drainfields and boreholes, deep well injection, evaporation-crystallization or other more exotic means. Second is the need to carefully consider feed water pretreatment prior to any subsequent membrane treatment.

The Tasks 11/13 study recommended a sidestream-operated RO demineralization operation in conjunction with STP effluent recycling efforts. While reducing the recycle flow salt level, the RO operation results in a concentrated salt solution blowdown. The use of vapor compression evaporation (VCE) to concentrate this RO blowdown stream was also put forth in the Tasks 11/13 study. In lieu of a separate salt concentrating operation and, assuming the domestic recycle system as presented in the Tasks 10 and 11/13 studies are implemented, the RO blowdown stream could be wasted to the process wastewater system for treatment in a single salt concentrating system.

The purpose of this study is to review the salt solution handling alternatives for both the domestic and process wastewater streams. The study will make use of available calendar year (CY) 1989 water volumes and demands as documented in Tasks 10 and 11/13 (Figures 2 and 3).

2.0 CURRENT WATER MANAGEMENT PRACTICES

2.1 WATER SYSTEMS

The CY-1989 RFP water delivery system is depicted in Figure 2. As noted in Section 1.0, the Task 10 (ASI, 1991a) and Tasks 11/13 (ASI, 1991b) studies recommended the revised water balance depicted in Figure 3. These studies also described and displayed both the domestic and process wastewater collection, transport and treatment facilities.

2.2 WATER USAGE

Figure 3 depicts the reuse opportunities associated with existing air washers, cooling towers, laundry and Building 443 water use centers. Approximately 61 million gallons per year (MGY) of evaporative water loss can be met by recycling existing domestic wastewater flows. This would result in equivalent reduction in offsite water purchases from the Denver Water Board (DWB). Additionally, the use of surface water runoff and onsite groundwater makeup water sources could reduce offsite water purchases further.

2.2.1 Cooling Towers

All cooling towers at RFP are of the mechanical-draft wet tower type that provide cooling by heat transfer from recirculated tower air flow to the atmosphere. Of the total evaporative loss noted in Section 2.2, cooling tower operations account for about 85 percent or 52 MGY.

The existing wet recirculating cooling towers recirculate the same cooling water for many cycles (Figure 4). To prevent unacceptable buildup of contaminants/salts due to evaporation, a portion of the recirculating water is continuously blowndown. The cooling tower total makeup water requirement is the sum of evaporation, blowdown and drift (entrained water carried in the air stream). The makeup rate depends on the extent (cycles of concentration) to which water is concentrated in the tower. To replace the total water volume lost, the system requires makeup water and, assuming recycling, treated domestic wastewater. Figure 5 presents water requirements for a typical cooling tower, noting the decline in makeup water with more cycles of concentration.

From Figure 3, the RFP tower blowdown is approximately 17.0 MGY or about 30 gallons per minute (gpm). Corresponding tower feed water rates are about 57.3 MGY or abut 100 gpm. This results in a current RFP cycle of concentration = 110/30 = 3.7. Also, assuming a feedwater total dissolved solids (TDS) of 300 milligrams per liter (mg/l), the blowndown salt concentration would be about 1,100 mg/l. Cooling tower evaporation rates vary widely, depending on climate, cooling tower design and the extent to which the air cools the water without evaporation. The effects of ambient site wet bulb temperature and relative humidity on evaporation rates are depicted conceptually in Figure 6 (Holiday, 1982). As shown, evaporation can range between 0.5 and 1.0 pounds of water per 1000 British thermal unit (Btu) of heat rejected.

As a function of local climatology, sufficient water storage for both reuse water from the Building 995 STP and for UF/RO treated domestic wastewater must be available to compensate for the daily, weekly, and monthly variations (as well as any statistically valid departures from normal) in available evaporative capacity. Alternatively, the addition of evaporative capacity, (more cooling towers) to reduce water storage needs would be possible, as would the use of existing or future waste heat sources such as cogeneration heat. While beyond the scope of this study, these considerations must be satisfactorily addressed to balance RFP system water reuse opportunities. There is obviously an economic balance point between new reuse water storage, new cogeneration evaporative capacity, and new cooling tower costs as RFP water resources management variables.

As a final consideration, tower makeup water must be of a high enough quality to prevent the following:

- scale formation (calcium carbonate/sulfate/ortho-phosphate, silicates, silica);
- corrosion (general, galvanic, underdeposit, microbiological);

- excessive nutrients/organism growths (fouling);
- foaming (organics, microogranisms); and
- tower material deterioration (microbiological, chlorination, alkaline conditions).

The treatment facilities described and recommended in Tasks 10 and 11/13 studies effectively provide the requisite water quality for cooling tower and other non-potable uses.

2.2.2 Domestic Wastewater System

Proposed Building 995 treatment facilities to address reuse water quality requirements included biological treatment followed by continuous operation membrane filtration (UF) with sidestream membrane treatment (RO) for TDS and nutrient reduction (ASI, 1991a and b). Specifically, the STP upgrade recommendations include biological treatment using sequencing batch reactor (SBR) technology. This technology reduces ammonia and nitrate concentrations to downstream reuse treatment facilities. The addition of powdered activated carbon to this biological treatment step (at multiple locations) is further pretreatment for downstream membrane separation for water reuse. Flotation/filtration as further pretreatment prior to membrane separation represents the required effort to assure satisfactory downstream treatment. In essence, all raw wastewater quantity and quality variations typically encountered at the Building 995 STP are subjected to physical, chemical and biological treatment that minimizes downstream effects on processes and operations employed in water reuse i.e., UF and RO.

2.2.3 Process Wastewater System

Tasks 11/13 and Task 20, Domestic and Process Water Pipeline Leak Study, (ASI, 1991c), described the existing collection, transport and treatment system for process related wastewaters. Treatment includes neutralization, precipitation, flocculation and clarification prior to evaporation. These features are presented in Appendix A. Figure 7 depicts the process wastewater balance for CY-1989. The existing Building 374 multiple effect evaporator (MEE) was designed originally to process 21 MGY. Ongoing maintenance, repair, corrosion and normal wear has reduced its capacity to about 13-14 MGY. Product water from the evaporator is currently used for boiler makeup in Building 443 and for use in the Building 371 cooling tower.

Noted in the Tasks 11/13 studies was the critical nature of the Building 374 evaporator. Evaporator down time combined with solar evaporation pond closures, inadequate process water tankage and evaporation of interceptor trench and other difficult-to-process wastewaters all combine to suggest the need for additional evaporator capacity.

2.3 AVAILABLE EVAPORATOR SYSTEMS

Evaporator systems are provided in several process configurations for varying site energy requirements, climatology and for optimizing the removal of water specific to any individual site. Many configurations utilize Multiple Effect Evaporators (MEE) systems, in which vapors generated in each effect become the heat input for each succeeding effect to remove water; MEE's typically have from one to seven effects. Vapor Compression Evaporators (VCE), in which vapors are mechanically or thermally compressed to recycle heated vapors, has recently found wide application because of significant energy savings over multiple effect evaporators in water removal. Heat Recovery Evaporation (HRE) represents another water removal opportunity using waste hot water or oil to provide the energy for evaporation, sometimes accomplished under vacuum.

A complete knowledge of RFP energy use, including steam generation capacity, waste heat sources and other cost considerations are beyond the scope of this study. However, a conceptual evaluation of MEE and VCE (whether motor or turbine driven) indicates a significant cost advantage with VCE. This point is shown on Figures 8, 9 and 10 (Shaw, 1989). For example, assuming a steam cost of $4.00/MBtu and a six effect MEE, the cost of evaporation energy is $0.80/1000 pounds of water evaporated (120 gallons). The equivalent cost for turbine driven vapor compression (VCE_T) is $0.25/1000 pounds of water evaporated (compressor ΔT=17°F). This is less than 1/3 the cost of MEE. If motor driven VCE were utilized in lieu of steam turbine (ΔT=17°F), electrical energy costs would have to be less than about 2.7 cents/kilowatt hour to out-compete the turbine driven option. This information suggests that either motor or steam turbine driven VCE offer significant cost advantages over MEE. This statement must be viewed in the context stated earlier. A complete knowledge of RFP energy uses/sources was not available for this study. The unavailability of steam to drive a turbine VCE could limit this option for example.

Figure 11 portrays several evaporator system configurations that could be implemented at RFP to utilize existing steam and MEE capacity more effectively. An assumed input salt concentration of 10% (100,000 mg/l) evaporated to 52% (520,000 mg/l) are illustrative only. Much lower feed concentration can be accommodated as well as final salt concentration. Typically, RFP feed brines range between 5,000 and 22,000 mg/l. Use of low grade heat such as cogeneration heat concentration prior to parallel VCE (new) and MEE (existing) represents an alternative with considerable cost saving potential. The effect of VCE or MEE feed solution concentration on water removal requirements, and therefore steam or electrical costs, is shown in Figure 12. In each of the evaporator systems described, blowdown salt solutions would be handled using saltcrete containment for off-site shipment. This discussion would be incomplete without a brief consideration of evaporation system operation and maintenance problems. The existing 4-effect MEE system at RFP experiences scaling of heat exchanger surfaces while concentrating brine solutions from 0.5-2.2 to 35%. The use of VCE as an alternative would most probably utilize a horizontal-tube, forced circulation, falling film evaporator, under vacuum, in conjunction with seeded brine feed and brine blowdown crystallizer. Most importantly, specific site circumstances dictate the use of certain technologies and equipment, irrespective of general applications described herein. Specific site knowledge was unavailable and beyond the scope of this study.

2.3.1 Other Concentrate Disposal Options

In light of potential energy saving, it is recommended that an RFP energy audit be conducted, with a comprehensive evaluation of RFP energy use and how energy needs might be met by cogeneration. Steam from a cogeneration system is a heat source option which could be utilized to concentrate/evaporate various wastewater solutions. Such a flexible system could result in a least cost combination of cooling tower makeup water storage, cooling tower capacity and cogeneration steam as water loss management options at RFP. The energy audit should be conducted in parallel with a cogeneration feasibility analysis.

While beyond the scope of this study, the feasibility analysis would evaluate the following (American Gas Association, 1982):

- conventional energy costs (electricity, oil, gas, steam) for next year of operation;
- rate that a cogenerator must pay for supplemental power purchased from electric utility;
- rate that a utility will pay for power sold by cogenerator to the utility;
- actual energy consumption and monthly billing demands for the site;
- description of the sites' existing equipment and service connections; and
- cogeneration equipment cost and performance information.

2.4 OTHER SALT/CONTAMINANT CONCENTRATORS

In addition to the use of waste heat to concentrate salt/contaminant streams prior to VCE and/or MEE, the use of RO has been proposed as a cost effective concentration alternative, either separately or conjunctively. In general, RO is more cost effective than VCE and MEE in producing a gallon of recovered product water at all scales of operation.

RFP implemented a water recycling program in 1979 following earlier RO pilot plant work (Plock, 1976). The RO plant treated wastewater effluent from the Building 995 wastewater plant. The purpose of this effort was to "contain the RFP water cycle" and minimize downstream wastewater discharge. At present, the Building 910 RO facility has been decommissioned and reportedly physically dismantled.

2.4.1 Pretreatment

Pretreatment of RO system feed enhances RO performance, protects membranes and minimizes membrane fouling. RFP has considerable prior experience with RO treatment problems, as documented in the following references:

	Publisher/Date	Title; Author
1.	Rockwell 5 and 6, 1983	Operations Report; Young
2.	Rockwell 9/19/83	Operations Report; Crossland
3.	Rockwell 10/2/84	Operations Report; Rose
4.	Rockwell 10/18/83	Operations Report; Rose
5.	Rockwell 11/14/83	Operations Report; Rose
6.	Rockwell 12/19/83	Operations Report; Rose
7.	Rockwell 5/2/84	Internal letter; Smith et al
8.	Author/Date Unknown	Abstract re: Bldg 910 RO Plant Problems

Most problems with the RO system were related to inadequate pretreatment and lack of RO brine concentration capacity in the Building 374 facilities. There was also a lack of storage for RO product water to meet varying seasonal demands (Detamore, 1988).

If the recycle/reuse program presented in this study and the preceding Tasks 10 and 11/13 studies is to be implemented it must be conducted in a manner that addresses each of the following factors that typically limit treatment facilities performance (EPA, 1984):

- operator application of concepts/testing to operations/process control;
- wastewater treatment/pretreatment understanding;
- technical guidance; consultants and suppliers;
- an effective maintenance management system; and
- administrative support.

2.4.2 Process Wastewater Pilot Work

The experience gained in utilizing RO for treatment/reuse of sanitary wastewater at RFP was also applied to a portion of the actual process wastewater stream. A mobile RO system was operated on the process wastewater stream and was "generally found acceptable" (Rockwell, 1979). With a feed TDS of approximately 5,000 mg/l, the RO system was able to produce a brine concentration of about 50,000 mg/l (5%); the brine stream contained total Alpha-Radiation, total Beta-Radiation and tritium concentrations of 43, 171 and <1,500 pico-curies/liter (pCi/l), respectively (Rockwell, 1981). These operations were conducted at an RO water recovery rate of about 80 percent.

As noted in Section 1.0, a comparison of RO and MEE was to be an important element of this study, with particular reference to the treatment (concentration) of process system wastewaters. Commercial development of RO has basically paralleled membrane technology improvements and module design. Membrane materials include cellulose and non-cellulose materials such as polyamides. Module configurations include spiral wound, plate and frame, tubular and hollow fibers. Key factors governing RO use include osmotic pressures, membrane characteristics, fouling tendencies, solution temperatures/concentrations and system configuration. It was decided early in this study effort however, that membrane separation of process wastewaters should not be considered in view of the highly variable quantity and quality of this wastewater source.

Also, it is important to recognize that RO by itself is not capable of matching either VCE or MEE in ultimate contaminant concentration. Subsequent concentration would be required with any use of RO. This is equally true for unit operations that typically compete with RO, including ion exchange and electrodialysis.

2.4.3 Domestic Wastewater Recycle/Reuse

Section 1.0 described the implementation of a domestic wastewater recycle system that would make use of a separate RO system to control reuse flow salt concentrations. Salt blowdown from this RO system could be conveyed to the process wastewater concentration options presented in this study, thereby negating two separate systems. This could be accomplished physically by RO blowdown to the process wastewater collection system.

2.4.4 Recommended Concentration Alternative

By way of brief review, Figure 13 depicts approximate water balances for both the sanitary and process wastewater systems.

A specific alternative for future contaminant concentration at RFP is based on the assumption that the existing MEE and saltcreting facilities would remain in service. Also, as noted in Section 2.4, the use of RO membrane separation on the process wastewater source is not appropriate. With these two major constraints in place the use of waste heat recovery and vapor compression evaporation linked with the existing MEE result in the alternative shown in Figure 14. Implementation of this VCE enhanced MEE evaporation system would increase the existing MEE system capacity by about 9 MGY to 22-23 MGY and provide much needed flexibility to this existing unit operation. The VCE unit could be equipped with a crystallizer such that, in the event of MEE system outage, a comparable brine product for saltcreting would be produced. The plumbing of VCE/MEE facilities for both series and parallel operation should be provided.

Figure 14 also depicts separate VCE concentration units for the solar ponds interceptor trench system (SPITS) groundwater management study, (ASI, 1991d) and landfill leachate water streams (ASI, 1991e). Concentrate brine from each of these VCE units would be further concentrated using a new VCE in conjunction with the existing MEE system. The use of waste heat concentration (by cogeneration if implemented) is not shown on Figure 14 but its use should be seriously considered in conjunction with the recommended energy audit. Figure 15 provides a VCE system component overview.

2.4.5 Solids Concentration Option

Earlier studies (ASI, 1991a and b) described a separate salt concentrating step for the water reuse RO brine blowdown stream (Figure 16). This figure also indicates the controlled introduction of surface and ground water inputs to balance seasonal water needs at the plant. In lieu of a separate brine concentrating operation the reuse/recycle brine could be blown down to the expanded capacity, linked VCE/MEE alternative described in Section 2.4.4.

2.5 OTHER CONSIDERATIONS

2.5.1 Reverse Osmosis Product Water

The question of comparability between RO product water and VCE/MEE recovered product water quality for boiler water feed (Bldg. 443) must be considered. No data were located on VCE/MEE recovered product water carryover or RO quality for the process wastewater feed, product or brine streams. Water quality from either system would appear to be comparable for boiler feed. At the present time, no further treatment of the existing MEE recovered product water is required.

2.5.2 Tritium

The pilot plant RO brine stream described in Section 2.4.2 contained <1500 pCi/l of tritium (${}_{1}^{3}H$). Site specific standards at RFP are 500 pCi/l (DOE, 1991). Hydrogen, being a gas, may be lost/stripped from any reuse treatment system at some point. Hydrogen (${}_{11}H$) and its isotopes deuterium (${}_{12}H$) and tritium ${}_{1}^{3}H$ are light insoluble gases, occurring chiefly in combination with oxygen as water. All isotopes of the same element have the same number of electrons and protons. Because isotope mass varies, the number of neutrons vary between isotopes. This suggests the presence of tritium in any water source as an undissolved gas or part of the water molecule. It is believed that there are methods available to remove tritium from water sources prior to loss from enclosed systems such as VCE/MEE. A pilot scale program to document this capability is recommended.

2.5.3 Other Radionuclides

Additional site specific surface water quality standards for Great Western Reservoir include gross alpha radiation and gross beta radiation of 5 and 12 pCi/L, respectively (DOE, 1991). Site specific standards for Great Western Reservoir for plutonium, americium and uranium are .03, .03 and 4 pCi/l, respectively (DOE, 1991). No specific knowledge is available on these radionuclides, for either feed, product or brine streams.

2.5.4 Post-Treatment

The use of RO, MEE and VCE water products typically require post-treatment for specific water reuse purposes. Whether treating pH, alkalinity, dissolved oxygen, TDS, foaming, trace organics, radionuclides or other quality issues, post-treatment requirements cannot be minimized. Point-of-use treatment most often addresses these issues. Such treatment requirements are beyond the scope of this study. Additionally, data required to address these issues was unavailable at the time of this report.

3.0 COST ESTIMATE

Treatment of RFP process wastewater results in a residual solids salt that is stabilized and solidified and then boxed and shipped offsite as saltcrete. Reducing the volume of upstream residual brines through water recovery and reuse is desirable because of installed evaporator capacity limitations, pressure to reduce operating costs and environmental requirements. Plants such as RFP that wish to optimize water recovery, minimize brine volumes and minimize energy costs are faced with a broad range of operation options.

For purposes of this cost estimate, the existing MEE is assumed to remain in place as are downstream saltcreting facilities. In addition to the MEE, new VCE (with crystallizer) is the unit operation recommended to concentrate waste brines, either singly or in series.

The CY-1989 RFP process wastewater volume was about 13.3 MGY (ASI, 1991b). If the domestic wastewater reuse brine plus surface and groundwater sources are added, a system capacity of about 15.1 MGY is indicated, this is about 30 gpm on an annual average basis. The actual capacity and condition of installed facilities at RFP are uncertain and were not confirmed. Also not confirmed were water and solid mass balances for existing system facilities. For these reasons the single preferred alternative has been structured as shown on Figure 14. Costs for this system, net of the solar pond interceptor trench water and landfill leachate treatment units, are as follows:

		Capital
VAPOR COMPRESSION EVAPORATOR (new)		$1,500,000
Feed, gal/min	30.0	
Feed solids, weight percent	1.2	
Water Recovery, gal/min.	25.5	
MULTIPLE EFFECT EVAPORATOR (existing)		$ 0
Feed, gal/min.	7.5	
Feed solid, weight percent	10.0	
Water Recovery, gal/min	5.0	
SPRAY DRYER (existing)		$ 0
		$1,500,000

The costs do not include any specific siting constraints at RFP, engineering/legal/ administrative costs or any contingency. This level of expenditure represents about a 9 MGY increase in the existing MEE capacity. Also, such an investment would reduce current annual utility costs for evaporation by roughly 50 percent.

The selection of any eventual concentrating system should be based on the energy audit described earlier, the condition and remaining life of existing cooling towers, the condition and remaining life of the existing MEE, the cogeneration opportunity and RFP's commitment to recycle/reuse of domestic wastewater effluent as proposed in the Tasks 10 and 11/13 studies.

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6.0 GLOSSARY

Alkalinity: By definition, total alkalinity (also called M alkalinity) is that which will react with acid as the pH of the sample is reduced to the methyl orange endpoint - about pH 4.2. Another significant expression is P alkalinity, which exists above pH 8.2 and is that which reacts with acid as the pH of the sample is reduced to 8.2.

Blowdown: The withdrawal of water from an evaporating water system to maintain a solids balance within specified limits of concentration of those solids.

Btu: British thermal unit

C: Centigrade degrees

cfm: cubic foot per minute.

cfs: cubic foot per second.

Chlorination: The application of chlorine, generally to treated sewage, to kill microorganisms that are discharged from the treatment plant with the treated sewage.

Cogeneration: The sequential use of a primary energy source such as oil, coal or gas to produce two useful energy forms, heat and power.

Concentration: The process of increasing the dissolved solids per unit volume of solution, usually by evaporation of the liquid; also, the amount of material dissolved in a unit volume of solution.

Contaminant: Any foreign component present in another substance; e.g., anything in water that is not H_2O is a contaminant.

Demineralization: Any process used to remove (salt) minerals from water.

Desalting: The removal of salt.

Dewater: To separate water from sludge to produce a cake that can be handled as a solid.

D.O.: Dissolved oxygen.

Effluent: The treated and clarified sewage that flows out of the treatment plant.

Evaporation: A widely used unit operation to remove water from aqueous solutions in a broad range of processing applications.

F: Fahrenheit degrees

Filtration: The process of separating solids from a liquid by means of a porous substance through which only the liquid passes.

Flocculation: The process of agglomerating coagulated particles into settleable floc, usually of a gelatinous nature.

Flotation: A process of separating solids from water by developing a froth in a vessel in such fashion that the solids attach to air bubbles and float to the surface for collection.

F/M ratio: Food-to-mass or food-to-microorganism ratio used to predict the phase of growth being experienced by the major microbial populations in a biological treatment process, such as activated sludge.

gal: gallon

gpcd: gallons per capita per day

gpd: gallon per day

gpm: gallon per minute

hp: horsepower

Influent: The untreated sewage that flows into the treatment plant.

kw: kilowatt

lb: pound

Membrane: A barrier, usually thin, that permits the passage only of particles up to a certain size or of special nature. Could include microfiltration, ultrafiltration, nanofiltration, reverse osmosis. Use of specific membrane is a function of intended use e.g., pretreatment, desalting, etc.

Microorganism: Organisms (microbes) observable only through a microscope; larger, visible types are called *macroorganisms*.

mg: million gallons, also milligram

mgd: million gallons per day

ml: milliliter

ug: microgram

Multiple Effect Evaporation: An operation in which the vapor generated in each evaporating effect becomes the heat input for each succeeding effect.

Neutralization: Most commonly, a chemical reaction that produces a resulting environment that is neither acidic nor alkaline. Also, the addition of a scavenger chemical to an aqueous system in excess concentration to eliminate a corrosive factor, such as dissolved oxygen.

Nitrification: A biological process in which certain groups of bacteria, in the presence of dissolved oxygen, convert the excess ammonia (NH_3) nitrogen in sewage to the more stable nitrate (NO_3) form.

Osmosis: The passage of water through a permeable membrane separating two solutions of different concentrations; the water passes into the more concentrated solution.

Oxidation: A chemical reaction in which an element or ion is increased in positive valence, losing electrons to an oxidizing agent.

pH: A means of expressing hydrogen ion concentration in terms of the powers of 10; the negative logarithm of the hydrogen ion concentration.

Pollutant: A contaminant at a concentration high enough to endanger the aquatic environment or the public health.

Polymer: A chain of organic molecules produced by the joining of primary units called *monomers*.

ppb: part per billion

ppm: part per million

psi: pound per square inch.

Reverse Osmosis: A process that reverses (by the application of pressure) the flow of water in the natural process of osmosis so that it passes from the more concentrated to the more dilute solution.

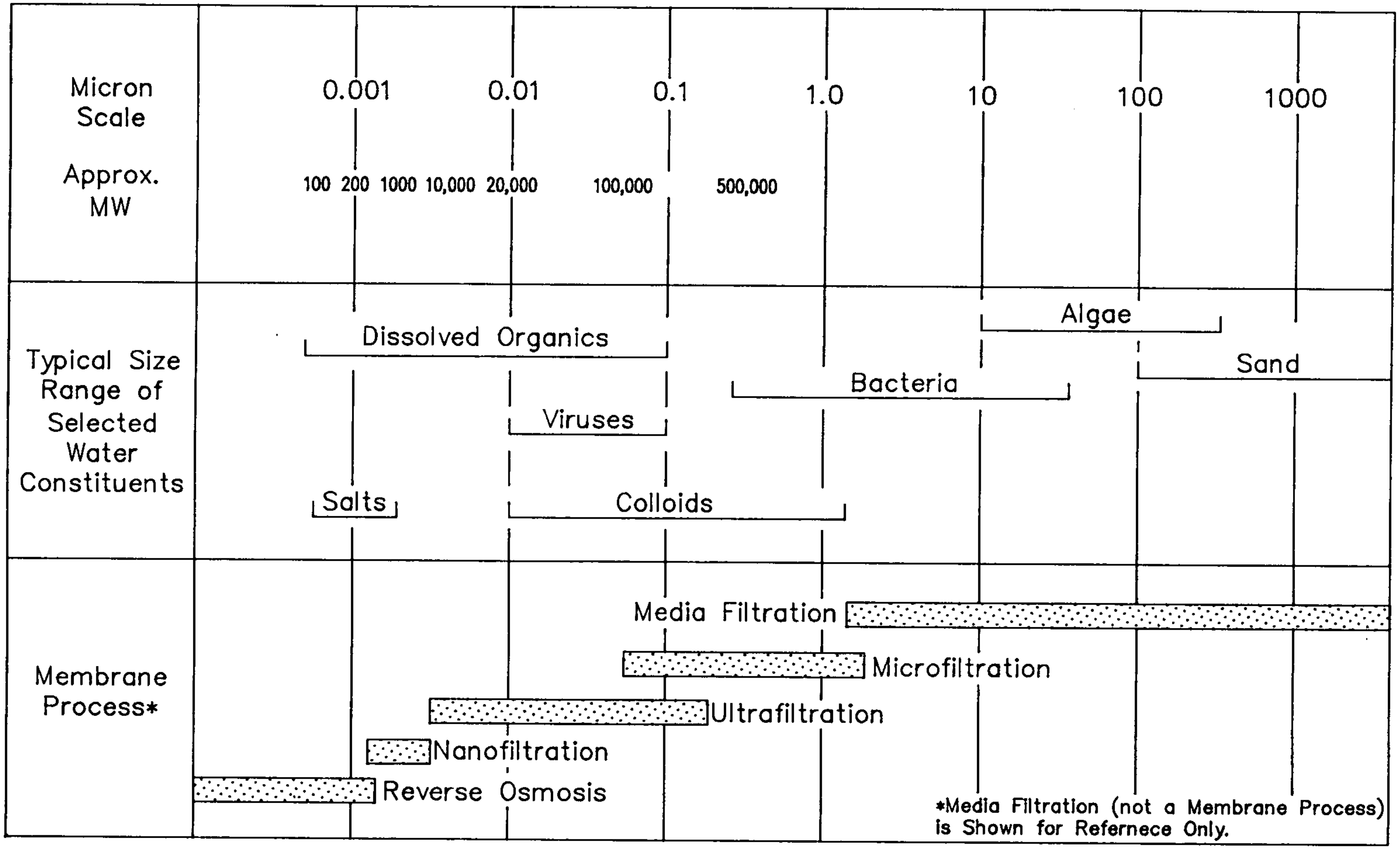
SBR: Sequencing Batch Reactor; one of many variations of the activated sludge wastewater treatment process.

Scale: The precipitate that forms on surfaces in contact with water as the result of a physical or chemical change.

Sedimentation: Gravitational settling of solid particles in a liquid system.

Sewage: Waste fluid in a sewer; water supply fouled by various uses through the addition of organic and inorganic material.

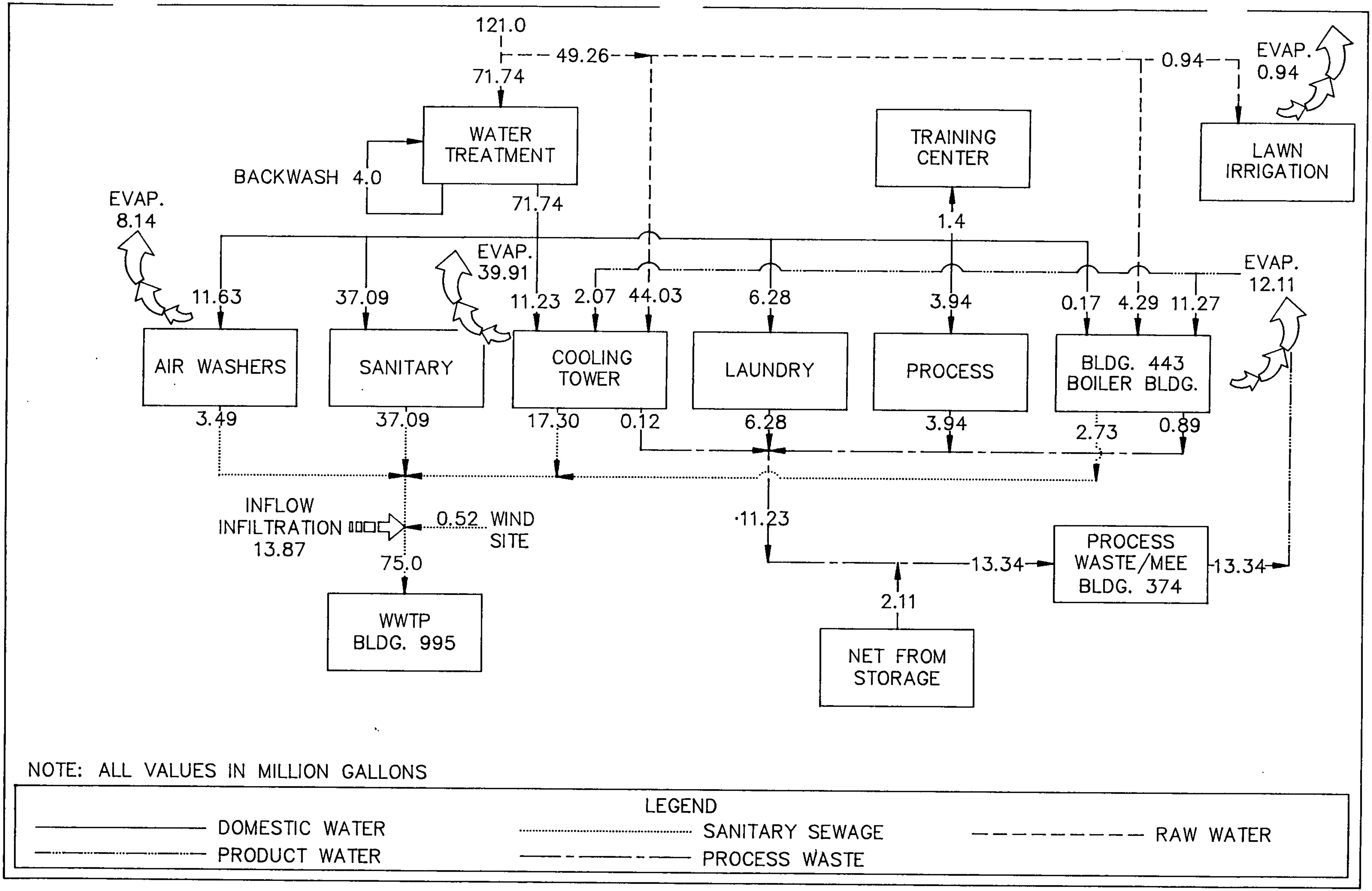
FIGURES



GENERAL PRESSURE–DRIVEN MEMBRANE PROCESS APPLICATION GUIDE

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

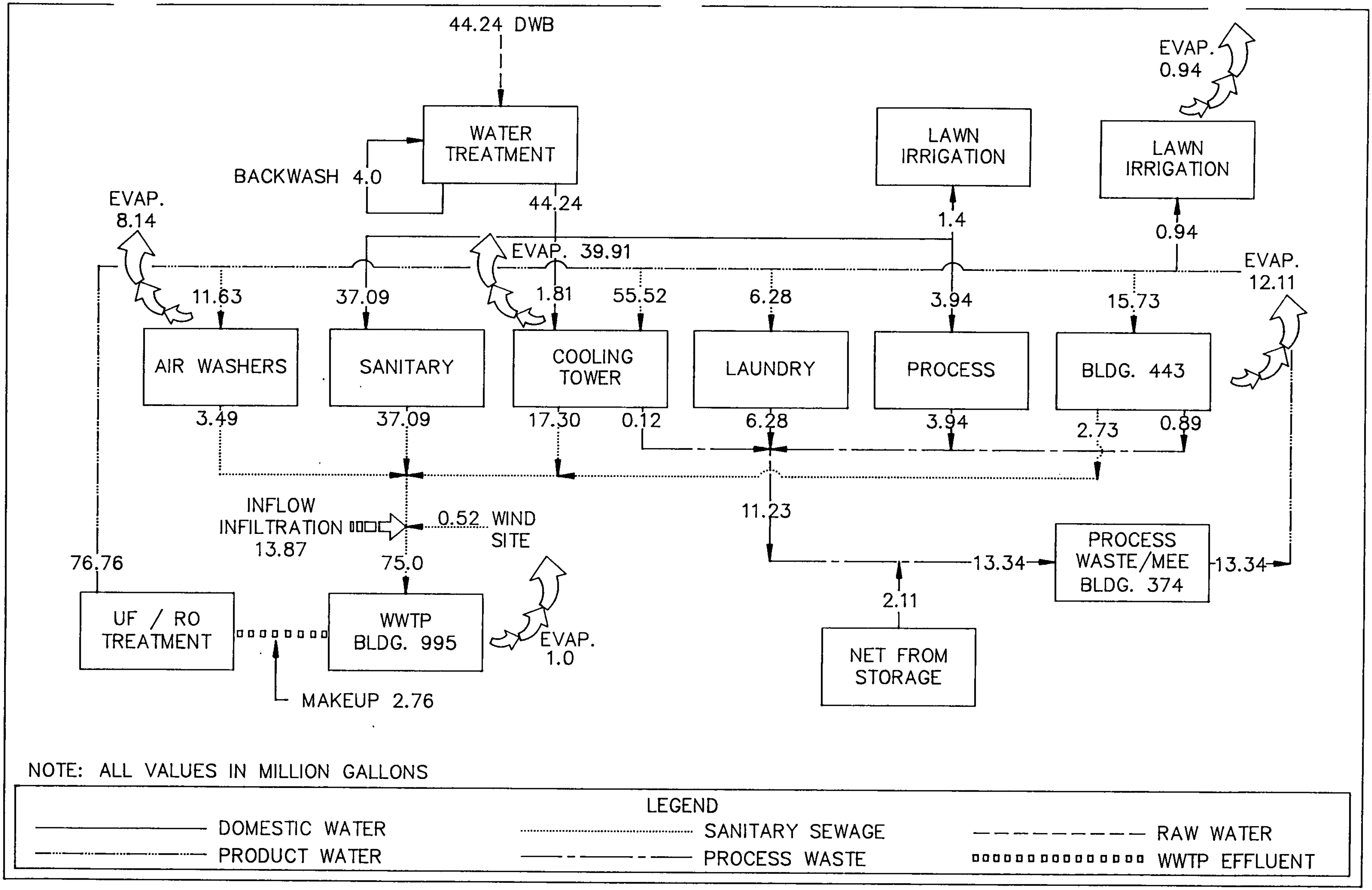
FIGURE No.1



WATER BALANCE CY-89

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

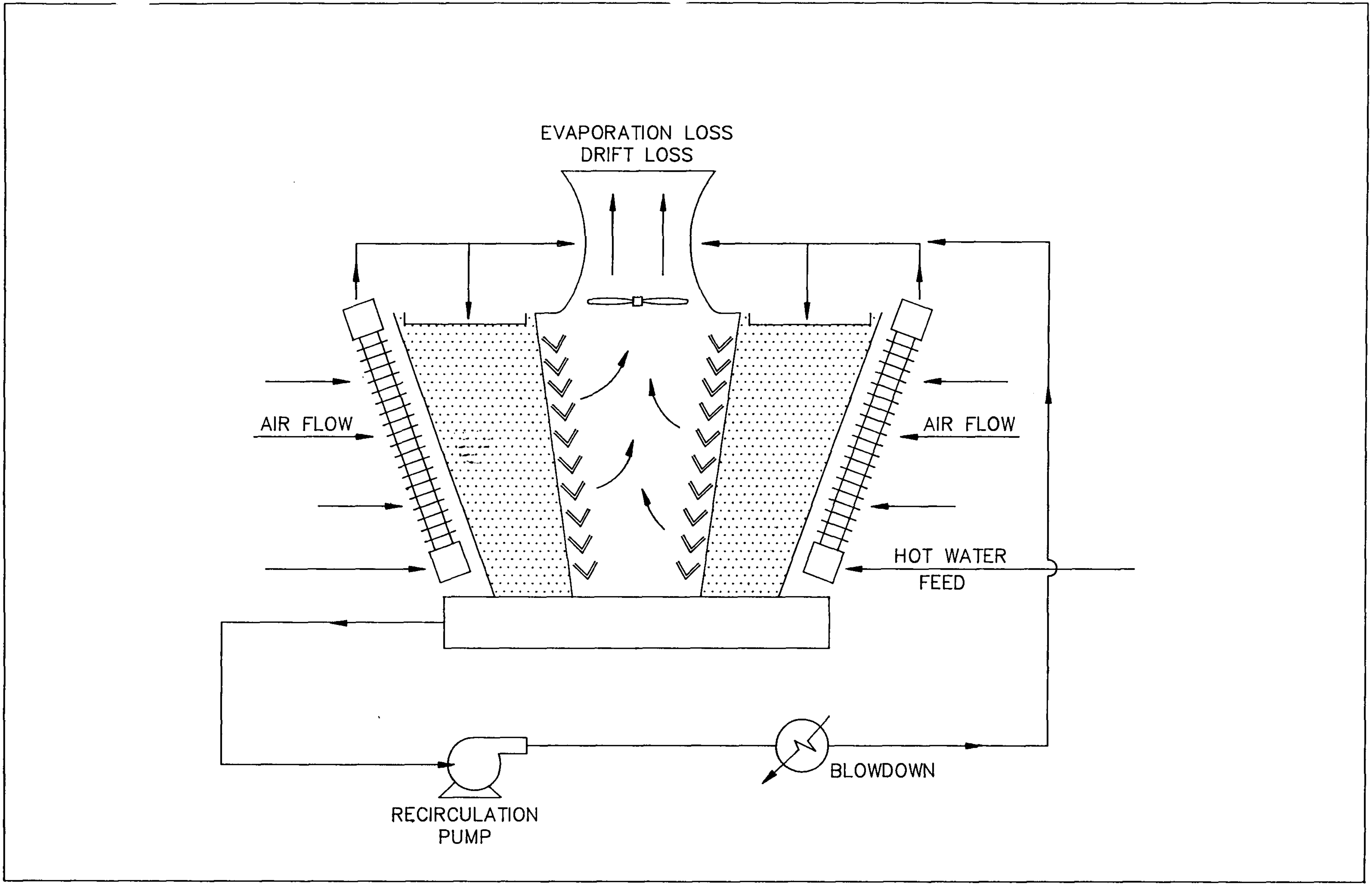
FIGURE No.2



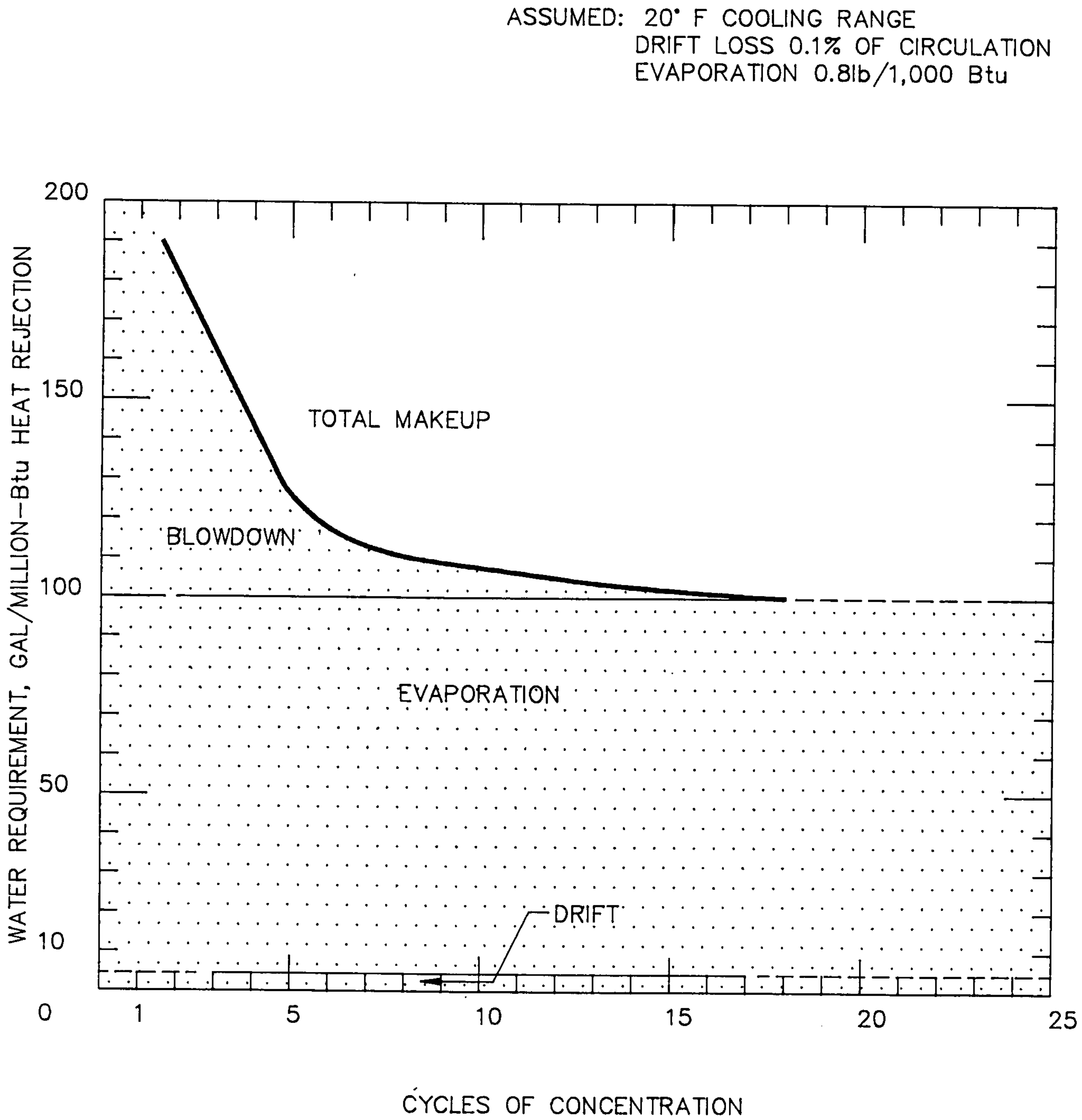
TASK 11 & 13 – RECOMMENDED ALTERNATIVE WATER BALANCE

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No.3



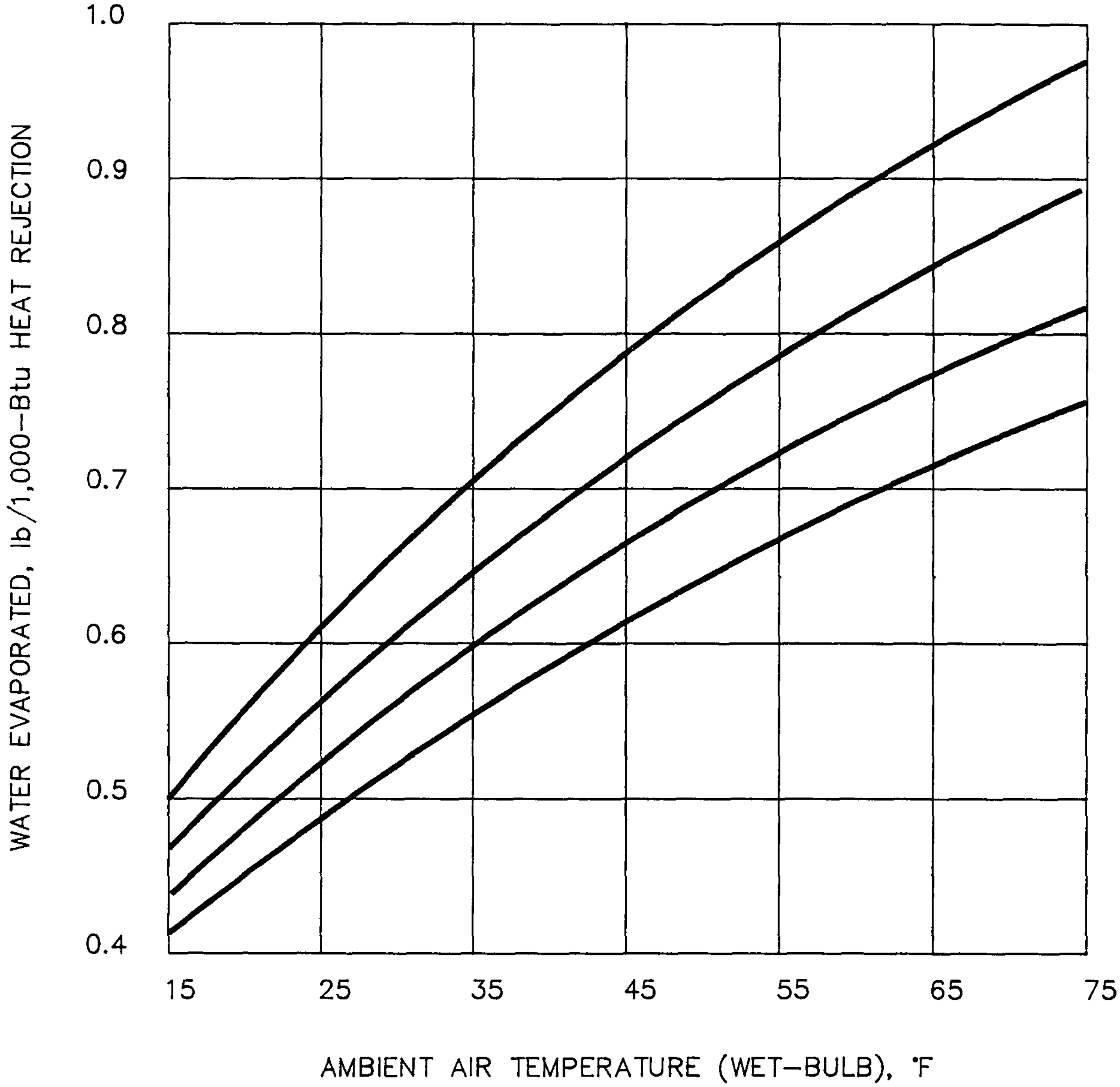
CONVENTIONAL WET COOLING TOWER COMPONENTS



COOLING TOWER WATER REQUIREMENTS

R.O. AND M.E. STUDY
ZERO OFFSITE WATER DISCHARGE

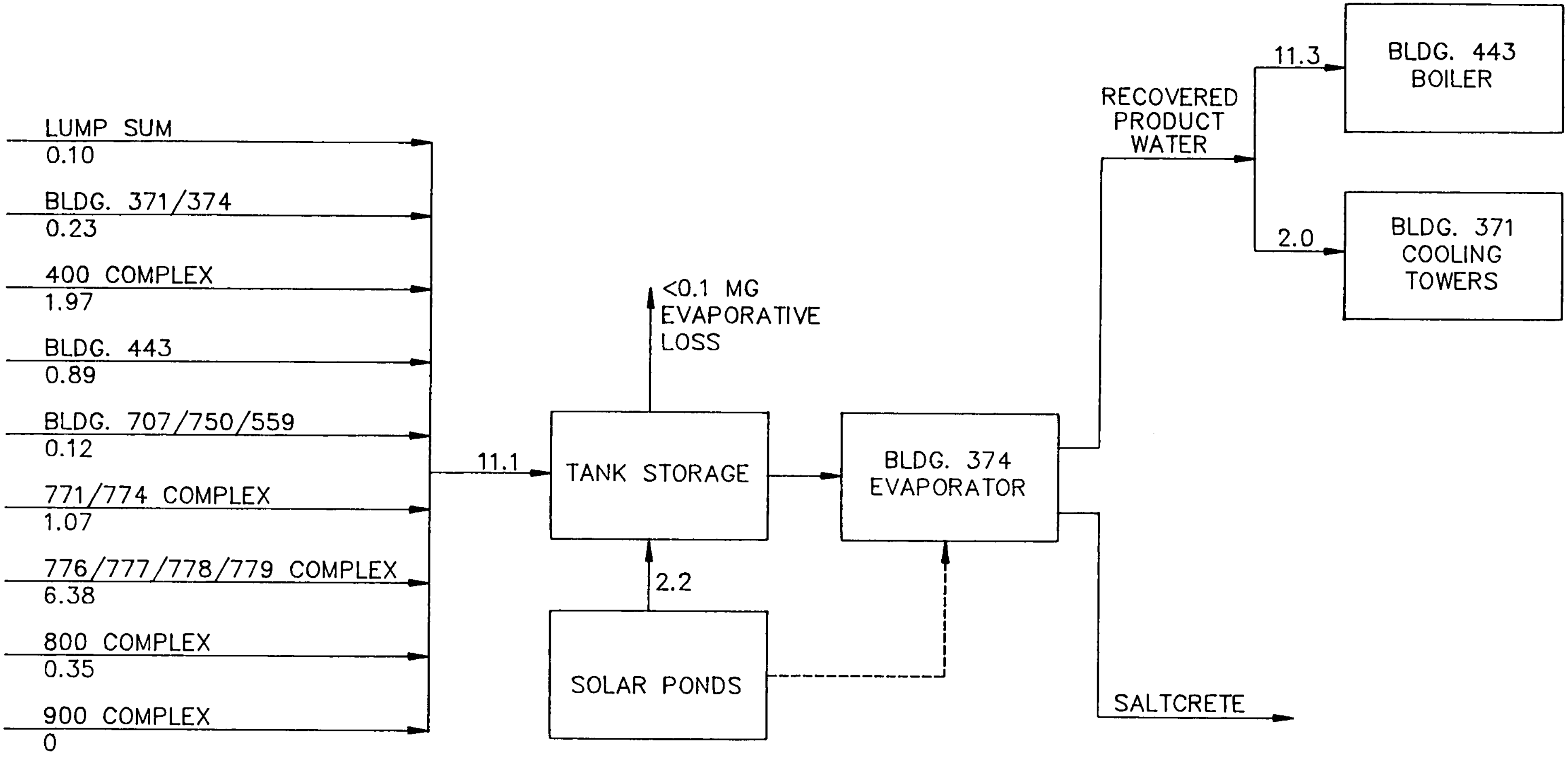
FIGURE No.5



EVAPORATION AS F (AMBIENT AIR TEMP. & REL. HUMIDITY)

R.O. AND M.E. STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No.6

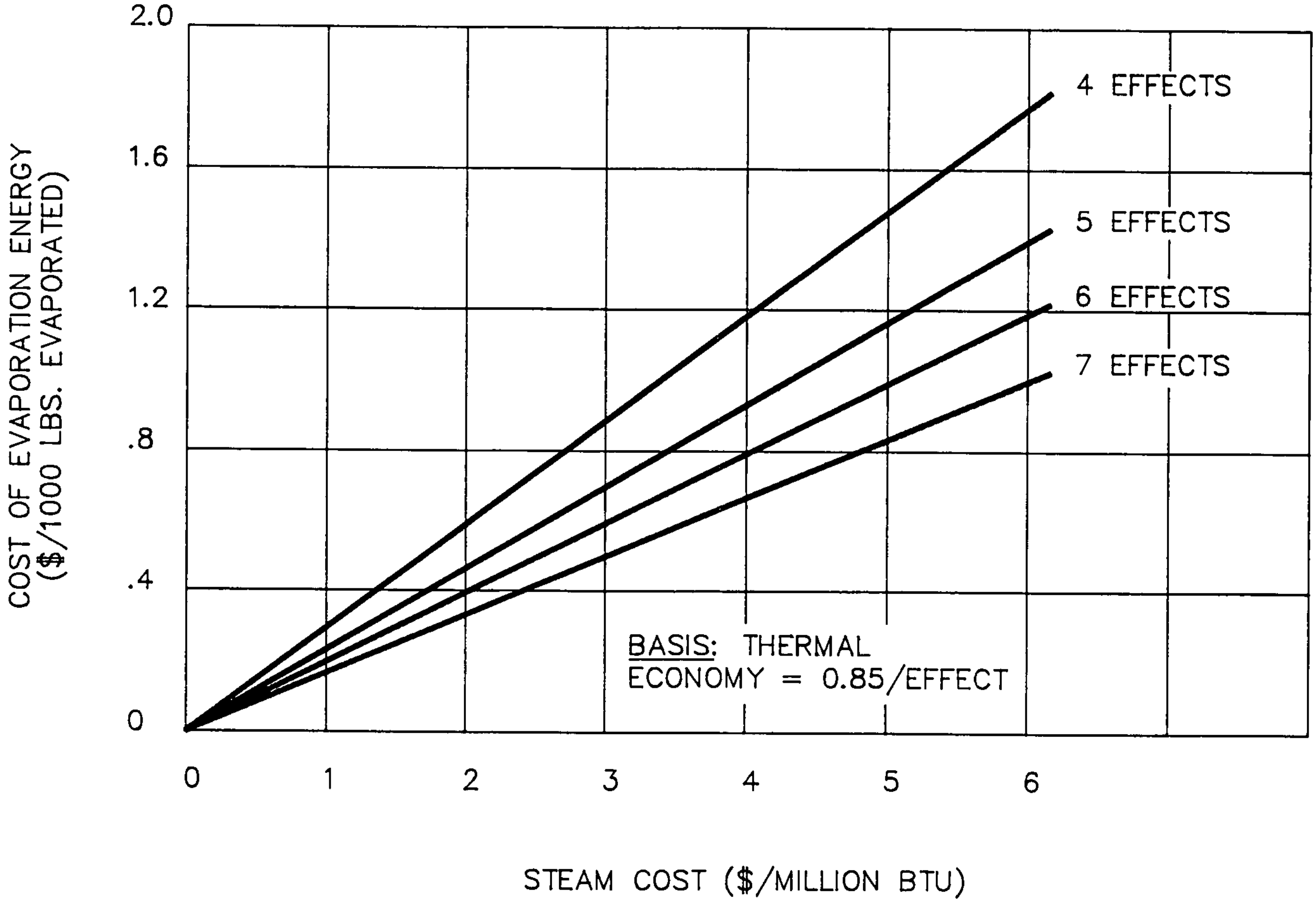


ALL VALUES IN MILLIONS GALLONS / YEAR

CY 1989 PROCESS WASTE BALANCE

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO-OFFSITE WATER DISCHARGE

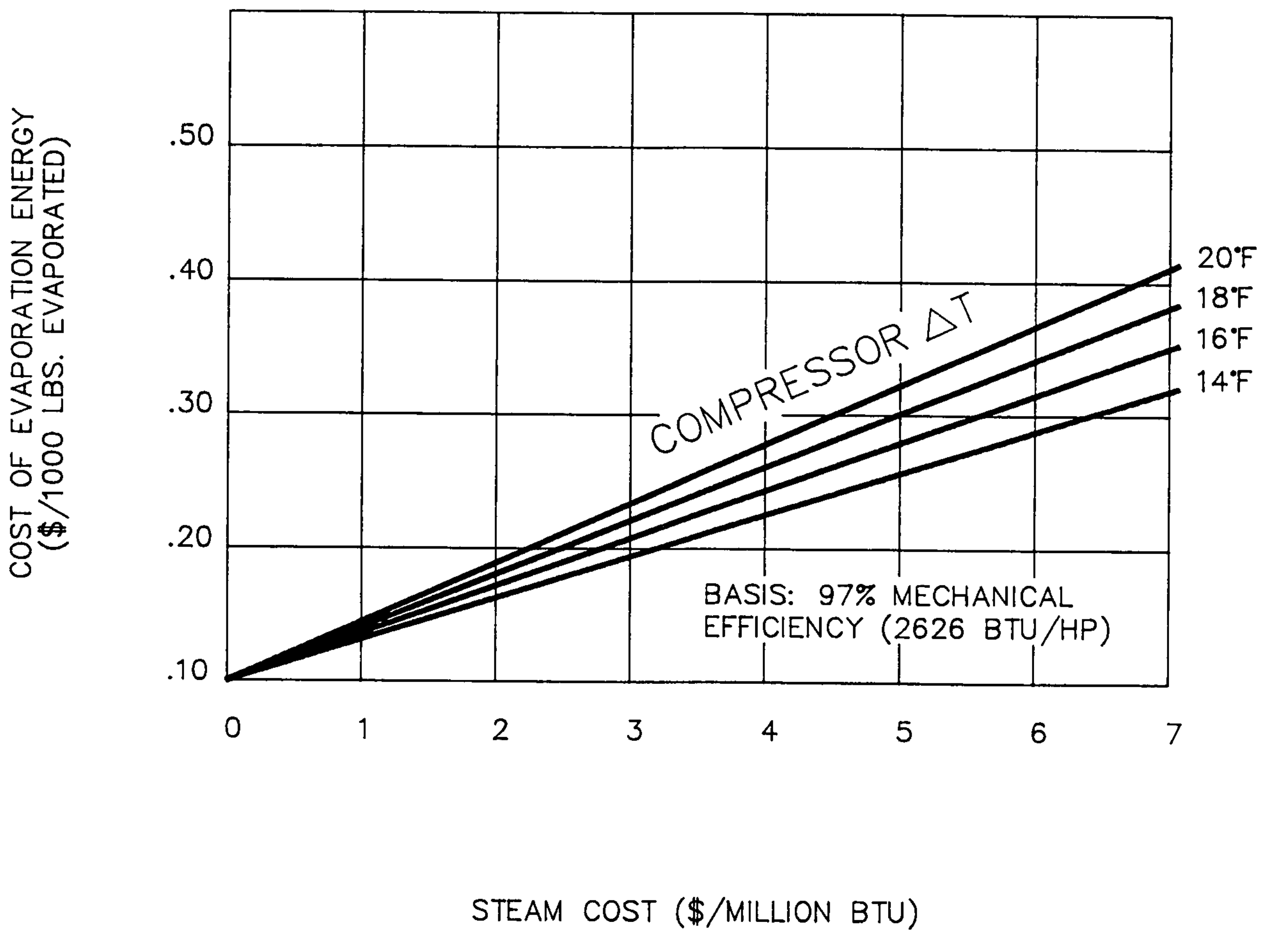
FIGURE No.7



ENERGY COST; FOR MULTIPLE EFFECT EVAPORATION

R.O. AND M.E. STUDY
ZERO OFFSITE WATER DISCHARGE

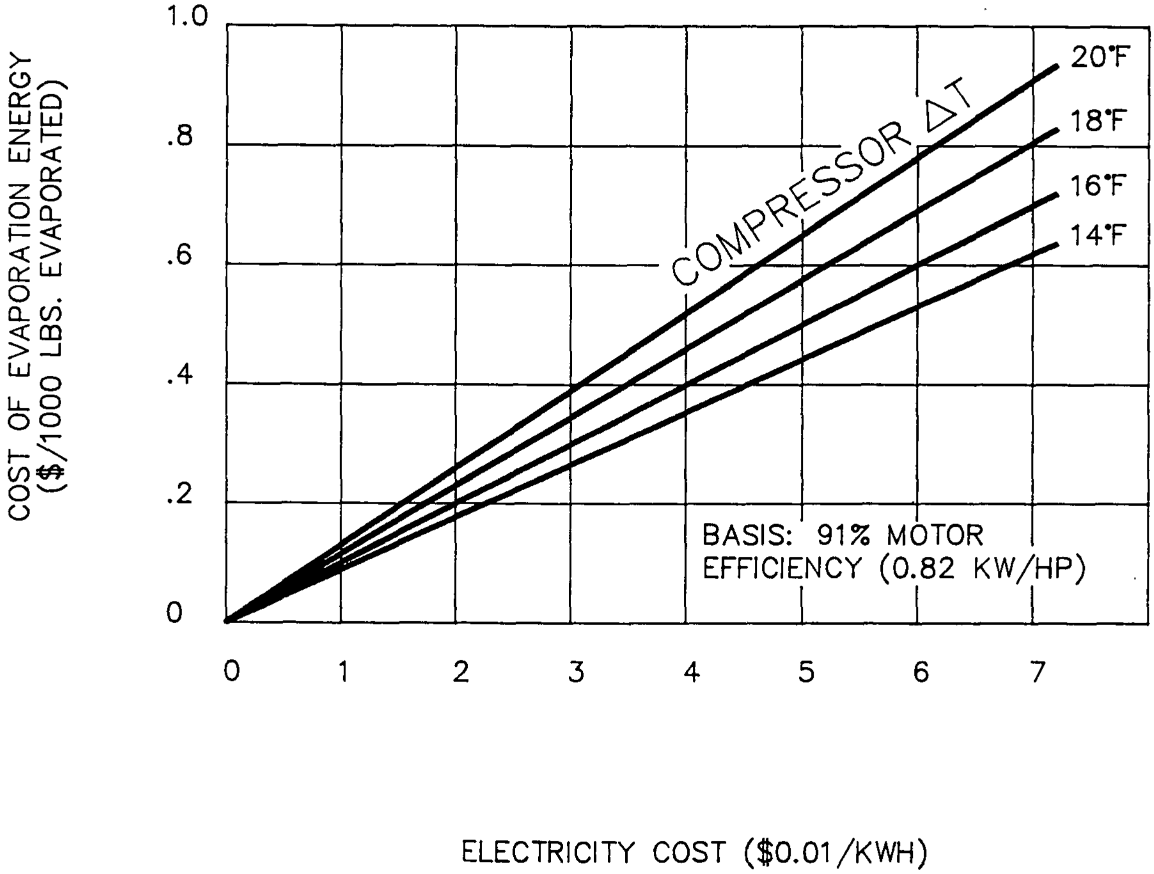
FIGURE No.8



ENERGY COST; FOR TURBINE DRIVEN COMPRESSION

R.O. AND M.E STUDY
ZERO OFFSITE WATER DISCHARGE

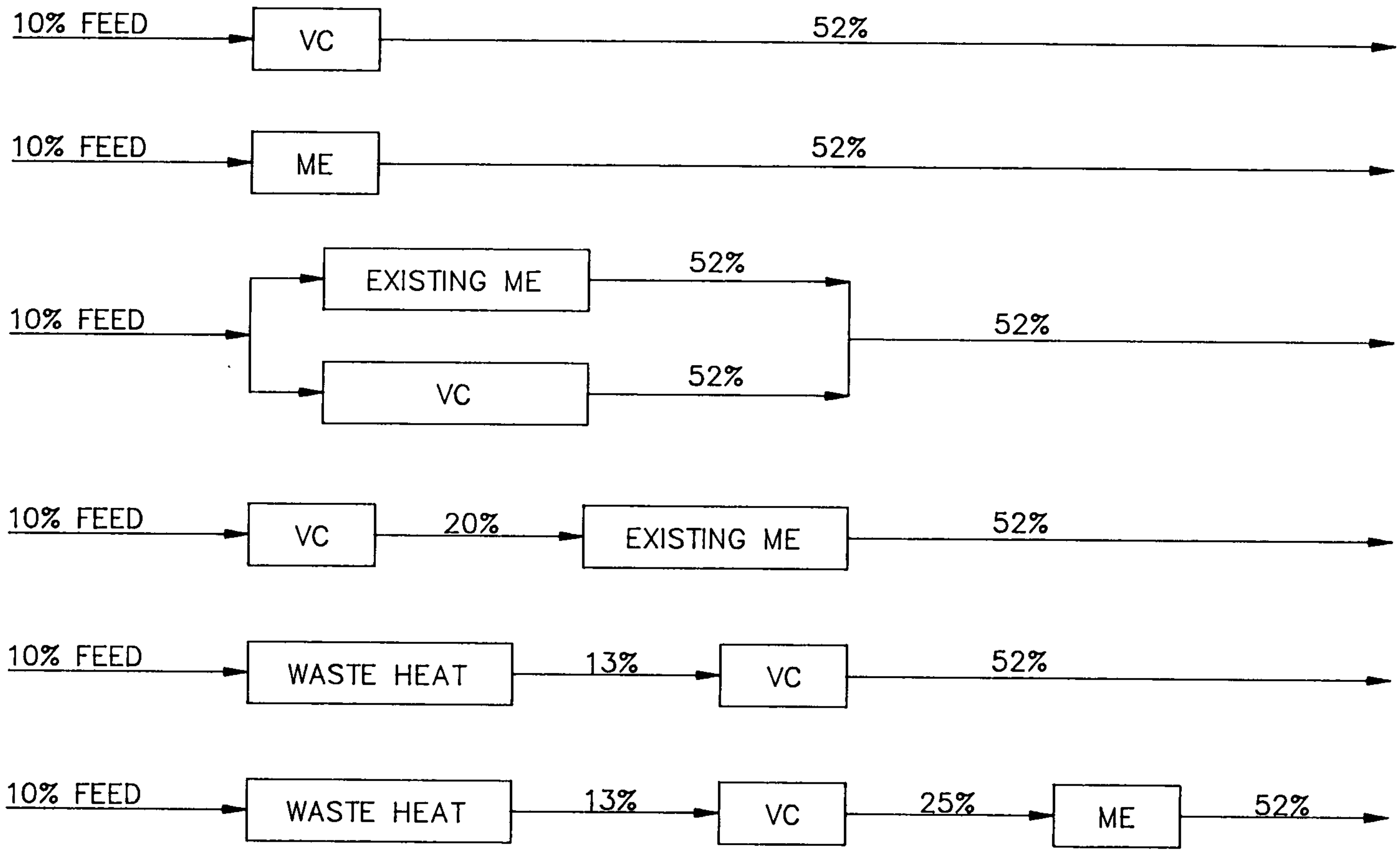
FIGURE No.9



ENERGY COST; FOR MOTOR DRIVEN COMPRESSION

R.O. AND M.E. STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No.10

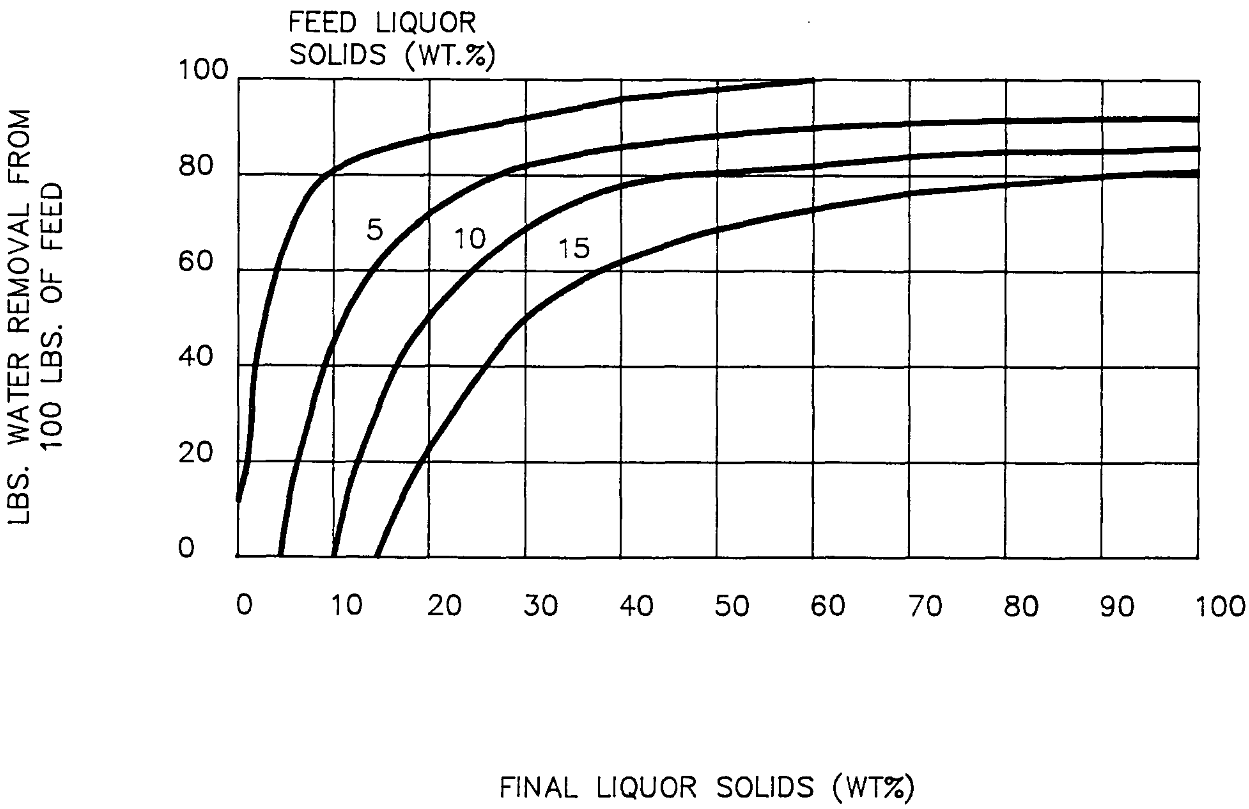


VC = VAPOR COMPRESSION EVAPORATOR
ME = MULTIPLE-EFFECT EVAPORATOR

TYPICAL EVAPORATOR SYSTEM CONFIGURATIONS

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

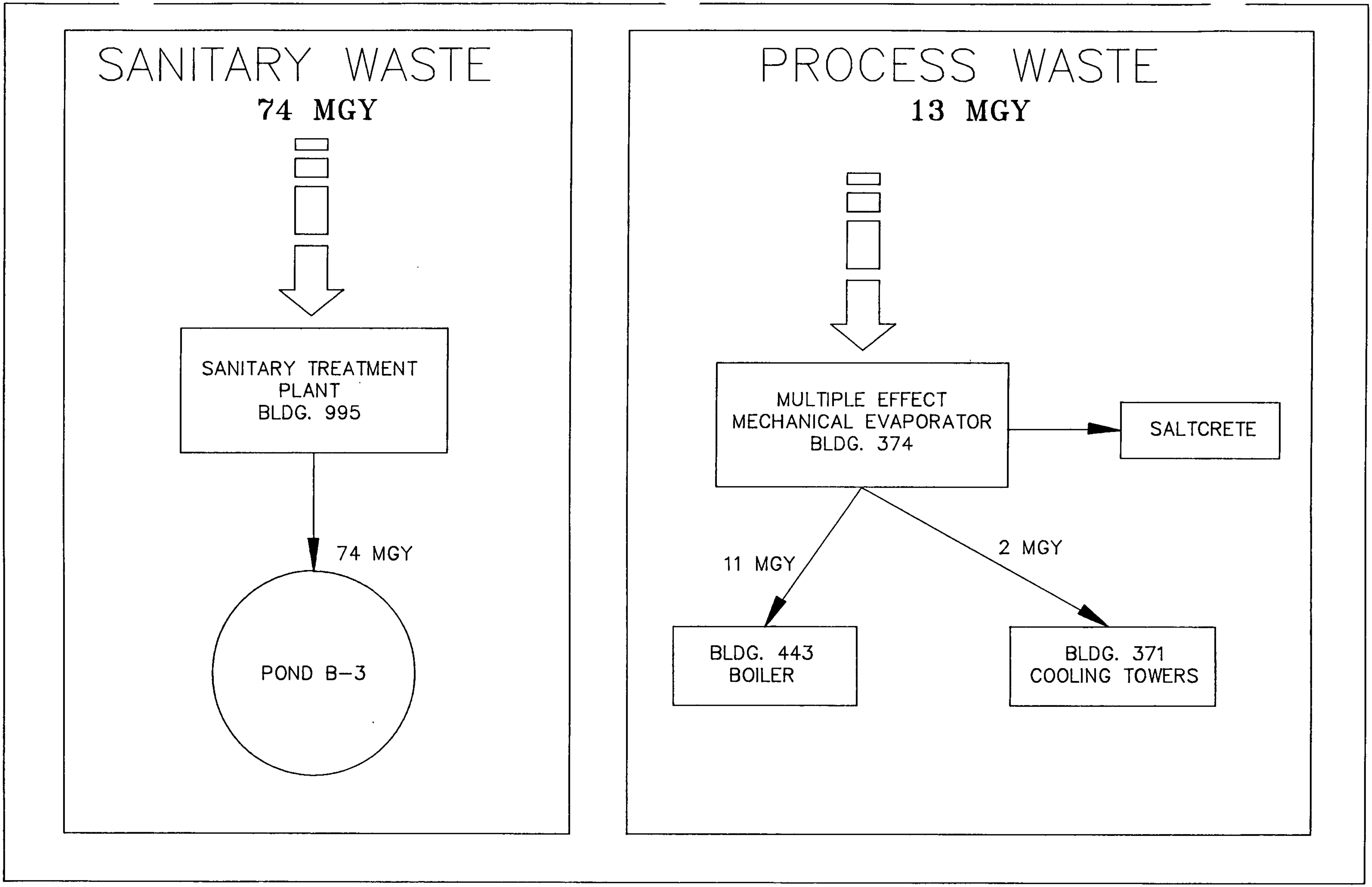
FIGURE No.11



WATER REMOVAL AS F (FINAL CONCENTRATION)

R.O. AND M.E. STUDY
ZERO OFFSITE WATER DISCHARGE

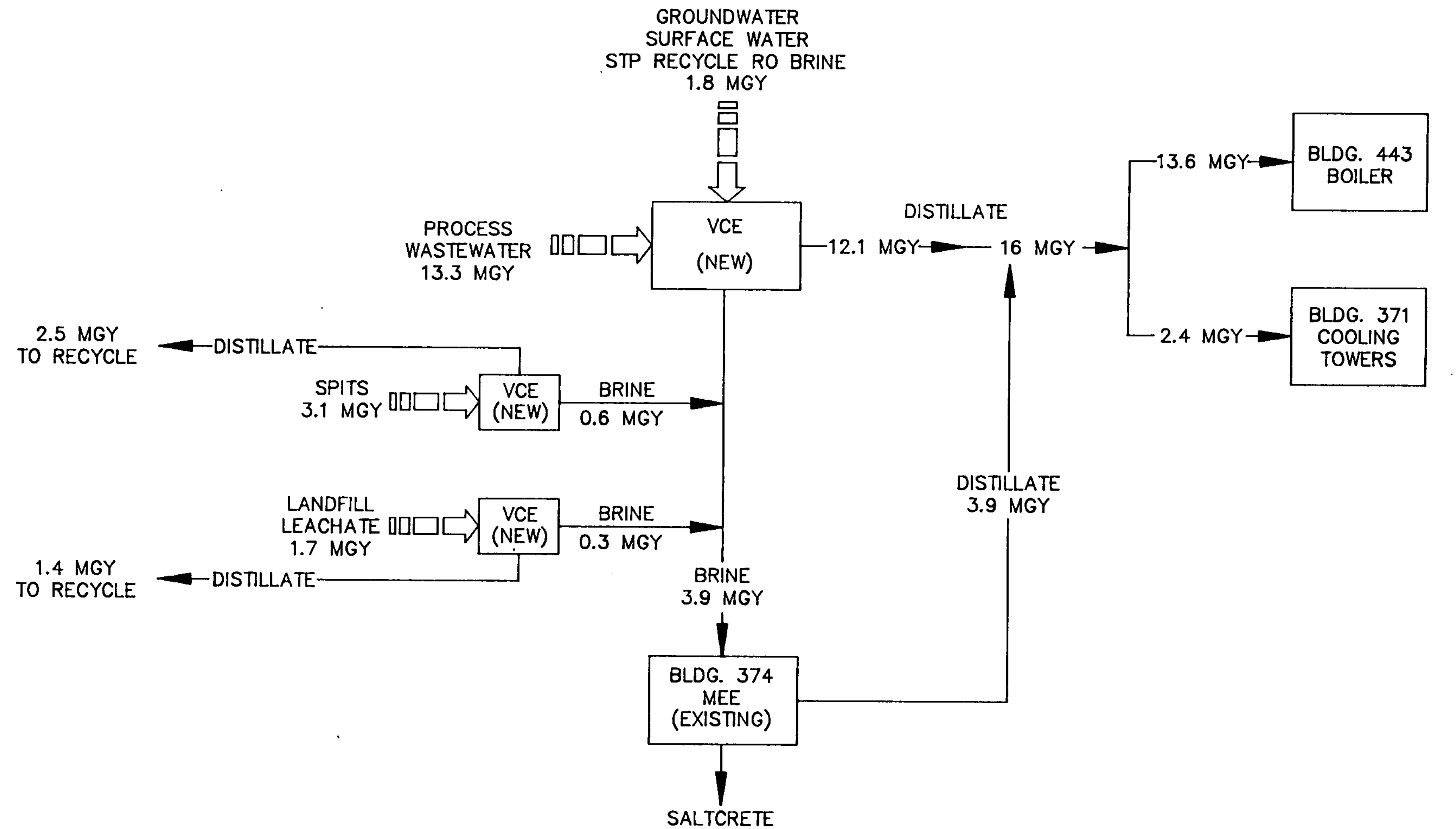
FIGURE No.12



CY 1989 CONFIGURATION

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No.13

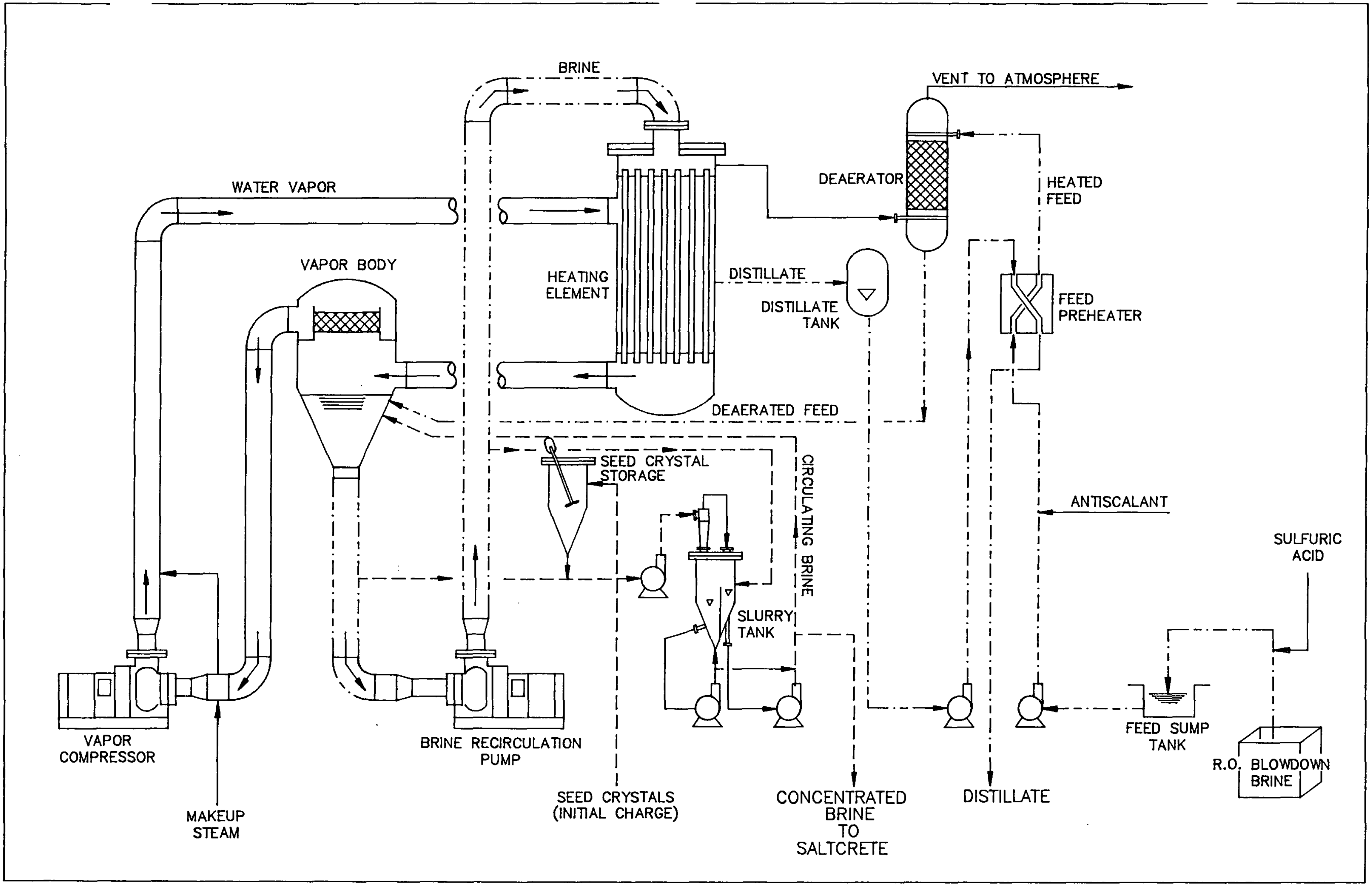


NOTE: MEE CAPACITY INCREASES BY 9.4 MGY

BUILDING 374 RETROFIT

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

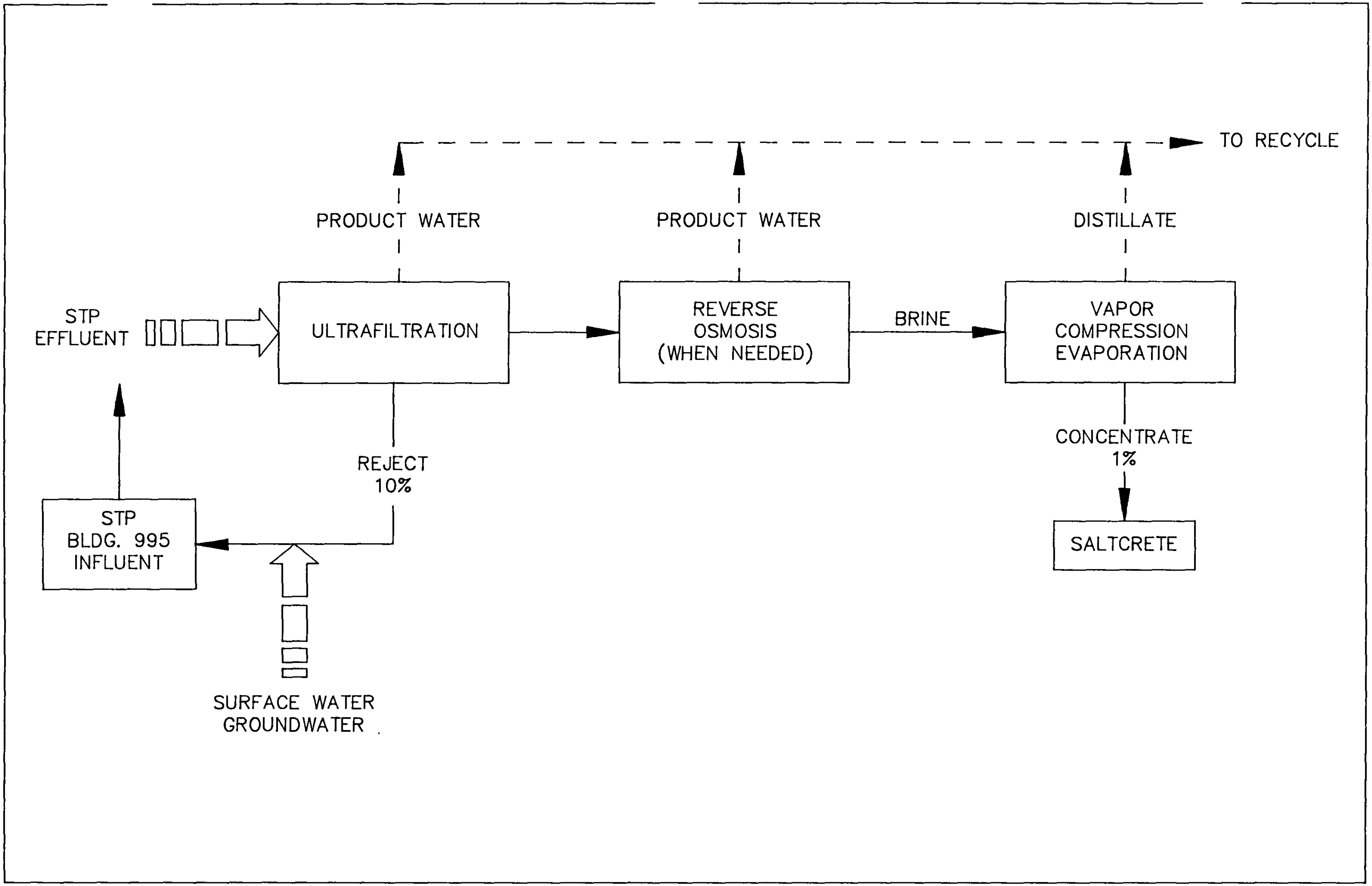
FIGURE No.14



VCE / CRYSTALLIZER

REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No. 15



SANITARY TREATMENT PLANT EFFLUENT SOLIDS STREAM

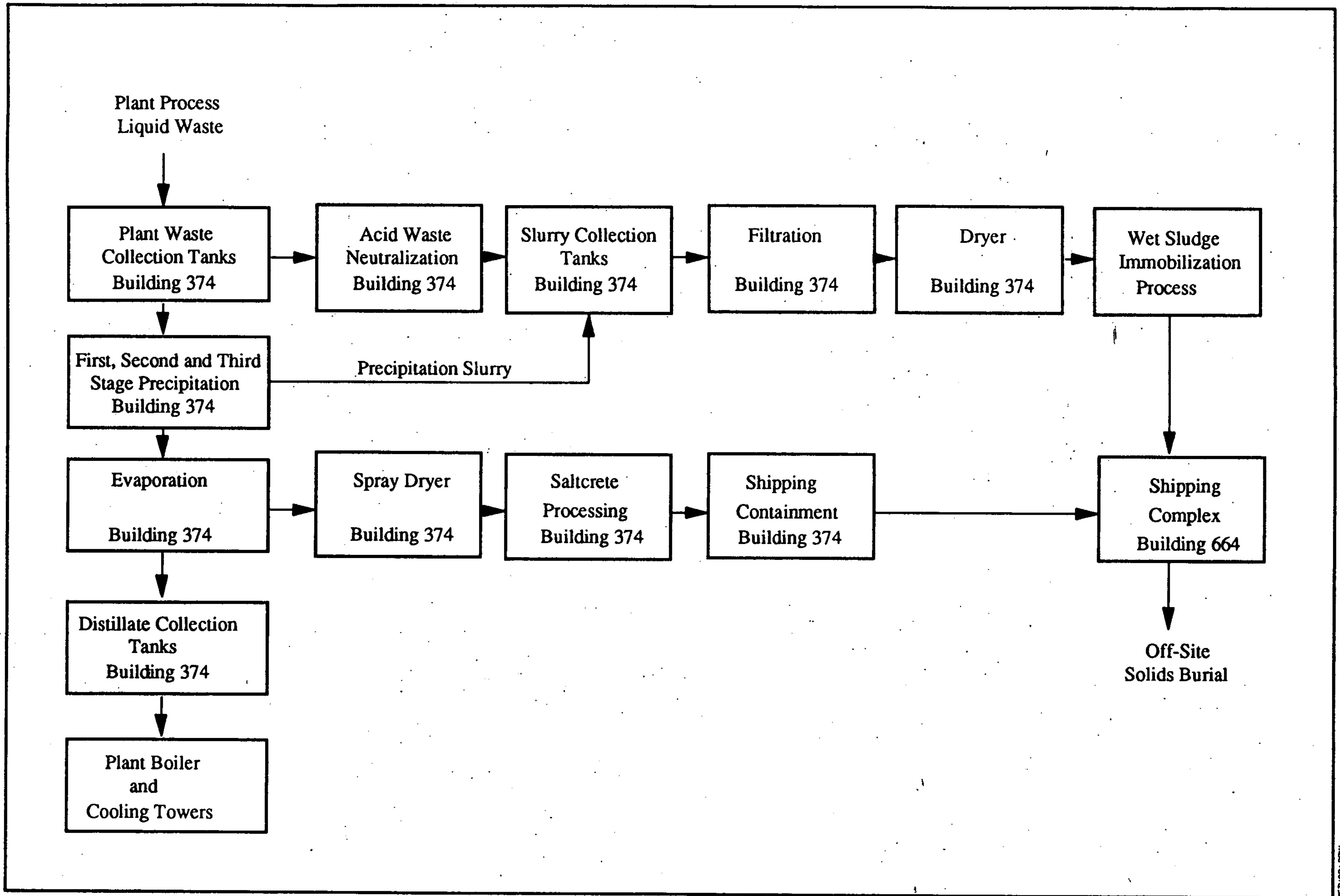
REVERSE OSMOSIS AND MECHANICAL EVAPORATION STUDY
ZERO OFFSITE WATER DISCHARGE

FIGURE No.16

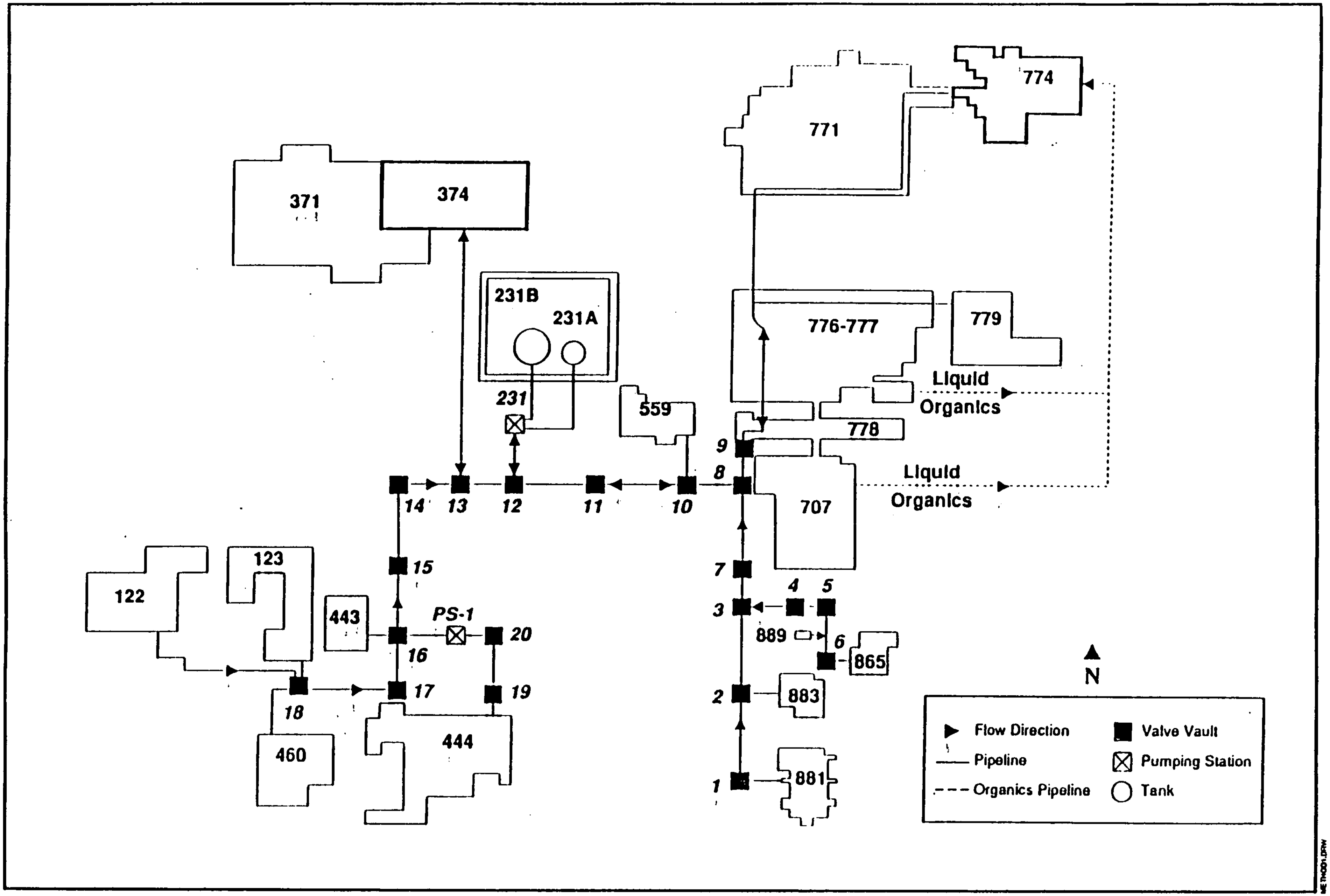
A

APPENDIX A

Process Wastewater Collection/Treatment Schematic



Building 374 Schematic



Process Waste Collection System

Reverse Osmosis/Mechanical Evaporation Study
Zero-Offsite Water Discharge

PROJECT 208.0112.60

FIGURE A-2